Engineering and Defense

PAUL COHEN

EIGHTEEN billion dollars, almost a quarter of our national income for the year, will be spent in 1941 on the defense of the nation. Fifteen per cent of our current industrial output consists of weapons or war materials for us or our allies. The second statement is significant; the first is not, for as Marcus Nadler recently remarked, appropriately enough to an audience of bankers, "National defense is not a financial problem. It is primarily the utilization of raw materials, machinery, and labor to produce the implements of war."

Here, preeminently, is the province of the engineer. Indeed he has even had a hand in the larger issues, for without such strictly technical achievements as the airplane, the submarine and poison gases, to mention only the most nakedly apparent, the gravest political and economic problems now facing this country could scarcely have come into being. The relation between war and technology, once covered more or less completely by the field of military engineering, which incidentally is the oldest of the engineering disciplines, is now so complex that it embraces virtually all the sciences and industrial arts. War today is the material and mechanical part of our civilization stripped to the bone.

In its demands for men, machines and materials, war is much like industry, except that its requirements are somewhat more restricted in form and far more complicated in structure than those of peace. None of the war effort, obviously, goes for lace curtains, permanent waves, jewelry, or the many other luxuries and conveniences which, en masse, make up an important part of peace-time industry. Relatively little is for canvas, canned foods, linoleum, pots and pans, or even lumber. The meat goes for heavy, intricate fabricated goods—airplanes, warships, tanks, trucks, artillery, powder, gasoline—and for the instruments of precision which detect or control these implements. And shortages develop primarily in metals, in machine tools to cut and form these metals, in chemicals, and in men who know how to handle them.

This is an engineer's war. More than ever the factors which determine the final decision lie in the laboratories, drafting rooms and factories of the home front, a front, by the way, of which no one was apparently aware until the last World War. Military engineering itself has been forced into the background, for its old concerns of transport, siege and demolition are increasingly obscured by a horde of mechanical and electrical devices. The extent to which highly engineered products, products which it would be virtually impossible to build except in a vast and highly developed industry, make up the demands of warfare may be demonstrated by a breakdown of the 37.3 billion dollars which the United States had appropriated for defense by the middle of 1941. (Total appropriations are now almost twice as large.) Sixteen and one-half billions, almost half of the total,

were for airplanes and their accessories; 8.8 billions for ships; 7.2 billions for guns, shells, and powder; 3.8 billions for additional industrial facilities to build this material; 3.3 billions for military posts, fortifications and defense housing; 1.8 billions for army equipment and 5.9 billions for food, pay and reserve materials for the armed forces.

Only in the last two categories, it will be observed, is there much scope for items with which engineers would not be concerned in one fashion or another. For the great bulk of these goods, the application of scientific laws and engineering practices marks every step from raw material to final utilization on the battlefield. Many of the raw materials are out-and-out synthetics; some, like magnesium and aluminum, are never found free in nature, and should thus also be considered man-made materials. Even iron, as iron, is a museum curiosity if picked up in the field.

The Army's 90 mm. anti-aircraft guns are said to contain 3,858 parts apiece. Each of these parts had to be designed with complete understanding of the functions it would perform in the completed gun, of the stresses it would endure and of the manufacturing means which could be used to make it. For each part a material had to be chosen out of the thousands available to the engineer and perhaps heat-treated to give it its optimum properties. Each had to be fabricated on tools and inspected with gauges which are frequently in themselves complicated engineering products.

Nor is one traverse of this road enough. The essence of technology is change and we may be sure that in a month, a year, or a decade a given weapon will be obsolete, forcing a new consideration of these factors. And there is no escape, for in no field, perhaps, is the penalty for slightly inferior products so severe; in no field must equipment operate with greater dependability, under more variable conditions or more reckless abuse.

Of necessity, therefore, the first ingredient in a successful weapon is research. From the President down, the leaders of this nation have publicly and repeatedly stressed that our research facilities, probably unequalled in quality (although perhaps exceeded in quantity by Germany and Russia), are one of our very greatest national resources. Since research is generally a slow process, with major results sometimes following a decade after the inception of a program, it would have been better, our hindsight tells us, to have begun that part of our defense program long ago. This was done to a limited degree, for the government of the United States, like most others having the means, has always expended a good share of its own funds for research on problems relating to defense. The work of the National Advisory Committee for Aeronautics is an outstanding example. Considerable research and development work have also been done by the civilian organizations which supply the armed forces in peace time. But because the number of men thus employed has been limited, because many of the problems now facing us could not be foreseen, and above all, because our task is to defeat an adversary of great technical competence, the research work we must do now will be limited only by the men and facilities available. These are now coordinated under the direction of a central agency, the National Defense Research Committee, an organization without a counterpart in this country in the last World War.

Many military problems are utterly new or so specific that little recorded work applies to them. Since the findings of pure science are on the whole more widely relevant, although less capable of immediate application than the results of research with more specific economic objectives, it is the pure scientists, particularly the physicists, who are in greatest demand. In this country a large part of the facilities of educational and endowed institutions is now employed on defense research contracts, and much the same situation is develop-

ing among industrial research organizations. Its corollary, of course, is a shortage of research on consumer products.

Luckily a large part of our peace time research accomplishments can be instantly and bodily turned over to military use. An advance in the metallurgy of magnesium, for example, is immediately applicable to military aviation. The creation of 100 octane fuels (they can scarcely be classed as gasoline) and the fabrication of plants to manufacture them on a large scale has been a peace time attainment with adequate economic justification, yet it gives the United States and whatever nations the United States cares to supply with these fluids a sharp advantage in plane performance. The advanced state of this country's radio industry has made it possible to put lighter, better sets in our transport planes than the apparatus found in captured German military planes. The development of methods for depositing microscopically thin layers of chemicals on glass surfaces so that reflection is cut down and transparency increased was intended to improve scientific instruments and camera lenses and to allow shoppers to get a clearer view of the inside of store windows. These coatings are now being used on bombsights, range finders, binoculars, sextants and other optical equipment for the armed forces.

A great increase in activity is occurring also in the designing of military equipment for, again, while the army and navy has always maintained an effective nucleus of professional military designers, it is pitifully small by comparison with the number of men which civilian industry can throw into this field, men just as carefully selected for ability and with their skill kept sharp by constant competition. In large measure the experience and creativeness of these men are directly transferable to the problems of defense. In planning and constructing new industrial plants, defense housing and merchant ships, the similarity with civilian practice is obvious. Even on highly specialized weapons, however, civilian designers are frequently showing that they need no handicaps in competition with men having greater familiarity with purely military equipment. In many cases no new factors are added to specifications with which they have already dealt. The equipment may be more rugged, the need for lightness more intense, the range of temperatures greater, but these are not fundamental changes. Scientific laws, after all, behave no differently when in the presence of a brigadier-general. And oil under pressure acts precisely the same in a medium tank as it does in a garbage truck.

Not particularly to the credit of the military forces is the appreciation which they appear to be showing for the aid furnished by large-scale participation of industry in their problems. Although on the basis of the record for the past century, recognition of the value of science and engineering to warfare should require no outstanding acumen, the military mind has generally fought a game but hopeless battle against technical innovations, and has shown an even fiercer resistance to the changes in tactics which frequently must follow if the new weapons are to function with maximum effect. As the course of this war indicates, research cannot stop with the placing of a weapon in production but must be accompanied by exploration of the weapon's tactical possibilities. Undoubtedly, the greatest contribution of science to warfare has been the scientific method.

Yet the visible bottlenecks in defense are not in the laboratories and drafting rooms but in production. (It may be mentioned that the public's fatalistic attitude toward the present inadequate defense against bombers is an illustration of how badly the research mentality has failed to penetrate its consciousness.) Quantity as well as quality determines the outcome, and in the rush to build the heavier battalions that comes in every war, shortages appear quickly in every production factor—materials, equipment and labor. Before this war

started, the Germans estimated that it would take eight men in the factories to keep a machine gun in the field, 40 men for a tank and 60 for a pursuit ship. To take a specific case, the manufacturers of the American pursuit ship known as the Airacobra state that, after various production improvements have been made, it still takes 8,000 man-hours to complete a ship, or the equivalent of one man working full time for four years. This does not include the man-hours required for the engine, the armament, the oil and fuel, the maintenance. The specific figures quoted by the Germans may be no more accurate than their published estimates of fuel consumption for a full dress war, but they indicate the nature of the labor problem in a modern conflict. On one hand are the armed forces clamoring for every able-bodied man they can get, the more technical training the better, for armies, too, have trucks to repair and lathes to run; on the other is industry with its need of more or less the same type of skill. Recently Parliament debated this same issue—whether to draft more skilled men into the army and improve its efficiency or leave them at their jobs and maintain the output of war goods. In many cases the army must win out, for armored divisions, aviation, anti-aircraft, signal and engineering corps might as well disband if they are not supplied with technically trained men.

The United States has not yet felt the labor shortage severely because its army, compared to its population, is not yet on the mass scale found in the actively belligerent countries, because its war industries are still far from hitting full capacity, and because there is still a great reservoir of unemployed and of workers being displaced from consumer industries. At present the highest average weekly employment in this country is 50.9 hours per week among workers in the machine tool factories. But British and German workers are already reported as working 60 hours per week and over. This means that they are probably at their limits of endurance. Further increases in weekly hours would only produce a slight lowering in output and would greatly increase the accident rate. Another sign of strain is the inclusion of women in jobs formerly held by men.

One answer to an insufficient labor supply is more efficient equipment, and one of the first tasks in arming a nation today is to equip its plants with the most productive machine tools available. Among other methods of preparing its industry, the German government in 1934 and 1935 permitted actual or potential armament plants to amortize new tools in 12 instead of the customary 240 months, a practice which was apparently quite successful in bringing these plants up-to-date. On the other hand, 65 per cent of the production equipment in American factories at the end of 1932 was reported as being 10 years old or older. Machine tools were the first items to be placed under full mandatory priorities in this country.

The civilian consumer is only dimly aware of this shortage, for the equipment needed to produce the types of goods he is directly interested in is already in existence. What worries him and the men who produce these goods is the increasingly severe shortages in certain materials entering into the construction of consumer goods. Actually, more raw and intermediate materials are being made than ever before, but the highly selective requirements of defense have increased so much faster than production that, in the case of magnesium and aluminum at least, there is not enough for all military needs, while for many other materials there is not enough to cover all civilian requirements. Mining companies can now use a rating of A-1-a, the highest defense rating, in obtaining materials for emergency repairs.

The materials now subject to priority ratings range from aluminum through borax, bronze, copper, cork, steel, pig iron, monel metal, vanadium and zinc, to mention but a few. Where suffi-

cient ore deposits exist within the borders of the United States, the problem is to create new mining, refining and fabricating capacity. This is being done for aluminum, magnesium and steel. The steel ingot capacity of the United States, already almost half of the world's output, is to be increased by 10 million tons a year, or by more than the total steel capacity of Japan. For minerals which this nation lacks, however, a practice successfully used by Germany and Russia is being followed. The country is being systematically scoured by geologists of the Bureau of Mines, and with some results, for new deposits of such minerals as antimony, chromite, manganese and tungsten. Since most of the ores are of sub-commercial grades, methods of processing them must also be developed. Germany has uncovered several oil fields in her own territory by large scale geophysical investigation, and the U.S.S.R. is reported to have spent 400 to 500 million rubles between 1929 and 1933 on geological surveying.

However, it is not to be expected that new reserves will be uncovered in sufficient amounts to affect civilian supplies appreciably. So far as these shortages are concerned, the consumer must either depend on the engineers to devise substitutes or do without. It is no exaggeration to say that the most universal problem now facing the engineers and designers still working on civilian products is that of substitution.

In many cases, the engineers are not yet pressed hard enough to make necessary any reduction in quality. Cast iron pistons and carburetor bodies are as good as aluminum and zinc if they are designed for the new materials, and many substitutes exist for the nickel steels which have also been eliminated from this year's automobiles. It is not merely a matter of changing the material specification on the blueprint, of course, for a cast iron piston needs different tolerances, somewhat different machining operations, and perhaps a heavier, better balanced crankshaft than an aluminum piston, but the new engine can perform as well as the old. To a more limited extent, radio engineers can substitute steel, paper and plastics, for the aluminum, zinc and nickel they cannot get, but many experts fear some decrease in quality. If aluminum cannot be obtained for pots and pans, enamel and pyrex can take its place with little disturbance except to the manufacturers. And in many essential products, the American public must remember, no changes are even threatened. There have been no important shortages in textiles, except for the disappearance of silk, a hole which is being ably plugged by nylon and various rayons. The American public faces no skimping in food, none in heating, little in gasoline.

As the shortages get worse, and undoubtedly they will, some products may be eliminated entirely, and many will be cut in quantity, as have automobiles, radios and refrigerators. Shortages have a tendency to grow. As manufacturers are denied zinc and copper they turn to lead, which itself becomes short. Increased demands on the plastics are counteracted by their relatively poor physical properties—their lack of strength, rigidity and resistance to high temperature—and by demands of munition makers for the same chemical from which some of them are made.

If these shortages irritate, however, we must look at the objective. We must, and will, defeat the greatest, most highly mechanized army in history. Superior mechanization will help us to do it. The material resources of the democracies are infinitely greater. Their manpower is greater. Plant for turning resources into armaments is still under construction, but it is being built on a scale so vast that Europe cannot equal it. Above all, it has the most skilled and perhaps the largest engineering force in the world, one which can produce weapons unmatched in quality and quantity. In the end this weight will tell, and when it does, the symbol of this victory will be not a sword but a slide rule.